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Review of geothermal energy resources in Pakistan

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Abstract

Pakistan, despite the enormous potential of its energy resources, remains energy deficient and has to rely heavily on imports of hydrocarbon products to satisfy hardly its needs. Moreover, a very large part of the rural areas does not have the electrification facilities because they are either too remote and/or too expensive to connect to the national grid. Pakistan has wide spectrum of high potential renewable energy sources, conventional and as well non-conventional. Many of them have not been adequately explored, exploited and developed. Geothermal energy is one of them. Pakistan can be benefited by harnessing the geothermal option of energy generation as substitute energy in areas where sources exist. Most of the high enthalpy geothermal resources of the world are within the seismic belts associated with zones of crustal weakness like the seismo-tectonic belt that passes through Pakistan having inherited a long geological history of geotectonic events. The present study of the geotectonic framework suggests that Pakistan should not be lacking in commercially exploitable sources of geothermal energy. This view is further strengthened by (a) the fairly extensive development of alteration zones and fumeroles in many regions of Pakistan, (b) the presence of a fairly large number of hot springs in different parts of the country, and (c) the indications of Quaternary volcanism associated with the Chagai arc extending into Iran and Afghanistan border areas. These manifestations of geothermal energy are found within three geotectonic or geothermal environments, i.e., (i) geo-pressurized systems related to basin subsidence, (ii) seismo-tectonic or suture-related systems, and (iii) systems related to Neogene–Quaternary volcanism. A few localities, scattered sporadically all over the country, have been studied to evaluate only some of the basic characteristic parameters of the geothermal prospects. The present review study the geothermal activities of varying intensity and nature, associated with different geotectonic domains, and reveals the viable potential of the geothermal environments, which could be exploited for the generation of sustainable indigenous energy in Pakistan.

Keywords: Geothermal energy; Geothermal resource characteristics; Geothermal potential in Pakistan

Contents

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1. Introduction

The energy sector plays a vital role in ensuring all-round development and growth of economy of a nation as the availability of adequate supplies of energy is a pre-requisite to generate economic activities. Energy is considered as one of the four major drivers of growth in strategic planning of Pakistan Government [1]. The other three drivers are agriculture, small and medium enterprises, and information technology. Since the inception of Pakistan, the primary power supplies from the conventional energy sources were (and are still today) not enough to meet the country's demand. Pakistan, despite the enormous potential of its indigenous energy resources, remains energy deficient and has to rely heavily on the imports of the petroleum products to satisfy its present day need.

The conventional energy sources, i.e., the fossil fuels, mega-hydels, and nuclear plants have remained the energy sources of choice in Pakistan for the decades (Fig. 1). Now, there has been a growing recognition, for more than one reason, of the dangers inherent in continuing with the model of economic development based on these sources, particularly the excessive consumption of the fossil fuels. One reason is that the reserves of fossil fuels are not unlimited and at the present rate of consumption they would not last very long. Moreover, it has been conclusively proved that climate change, which has been resulting in global warming, is mainly caused by greenhouse gas emissions from energy generating systems based on the fossil fuels. Yet, another aspect that has come into sharp focus is that the developing countries can ill afford to depend excessively upon petroleum imports as they are marked by volatile price fluctuations. Moreover, indiscriminate use of fuel wood leads to deforestation with consequent environmental hazards and inefficient burning of fuel wood leads to an increase in indoor air pollution.

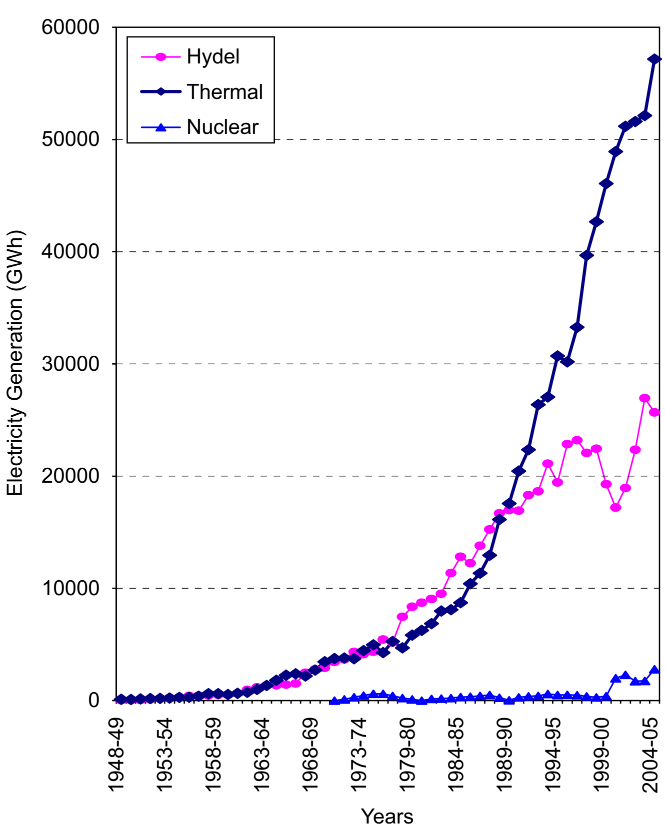

Fig. 1. Generation of electricity from 1947 to 2005 by hydel, thermal (oil, natural gas, and coal) and nuclear sources (in million kWh) [33,34].

Considering the geological setup, geographical position, climatological cycles and the agricultural activities, Pakistan has wide spectrum of high potential of renewable energy sources, conventional and non-conventional as well, which have not been adequately explored, exploited or developed. Geothermal energy source is one of them. Geothermal energy is the energy derived from the heat of the earth's core. It is clean, abundant, and reliable. If properly developed, it can offer a renewable and sustainable energy source. People have used geothermal resources in many ways, including healing and physical therapy, cooking, space heating, and other applications. One of the first known human uses of geothermal resources was more than 10,000 years ago with the settlement of Paleo-Indians at hot springs [2]. Geothermal resources have since then been developed for many applications such as production of electricity, direct use of heat, geothermal heat pumps, etc.

This paper describes the prospects for the geothermal energy sources in Pakistan with the view to attract the attention of the national and international investors for the development of geothermal energy generation technology that is presently at zero.

2. Tectonic framework of Pakistan

Pakistan stretches from 24° to 37°N latitudes and from 61° to 76°E longitudes (Fig. 2). The total land area of Pakistan is about 800,000 km^2. The northeast to southwest extent of the country is about 1700 km, and its east–west width is approximately 1000 km. The geomorphology of Pakistan varies from lofty mountains of Himalayas, Karakorum, Hindukush, and Pamirs in the north to the fascinating coastline of the Arabian Sea in the south. In between the northern and southern extreme ends of the country, notable, and unique bended north–south oriented mountain ranges exist centrally bounded by the fertile plains of 3000-long River Indus and western part of famous Thar Desert on eastern side, and by the Chagai volcanic arc, vast tectonic depression of Kharan, and the westward swinging mountain ranges of Makran flysch basin.

The tectonics of Pakistan is dominantly the result of various phases of collision, convergence and rift events (Fig. 2). It reflects the complicated pattern of competent and incompetent tectonic blocks as a whole. In the southwestern part of Pakistan, the dominant structural features strike eastward in Makran region and turn

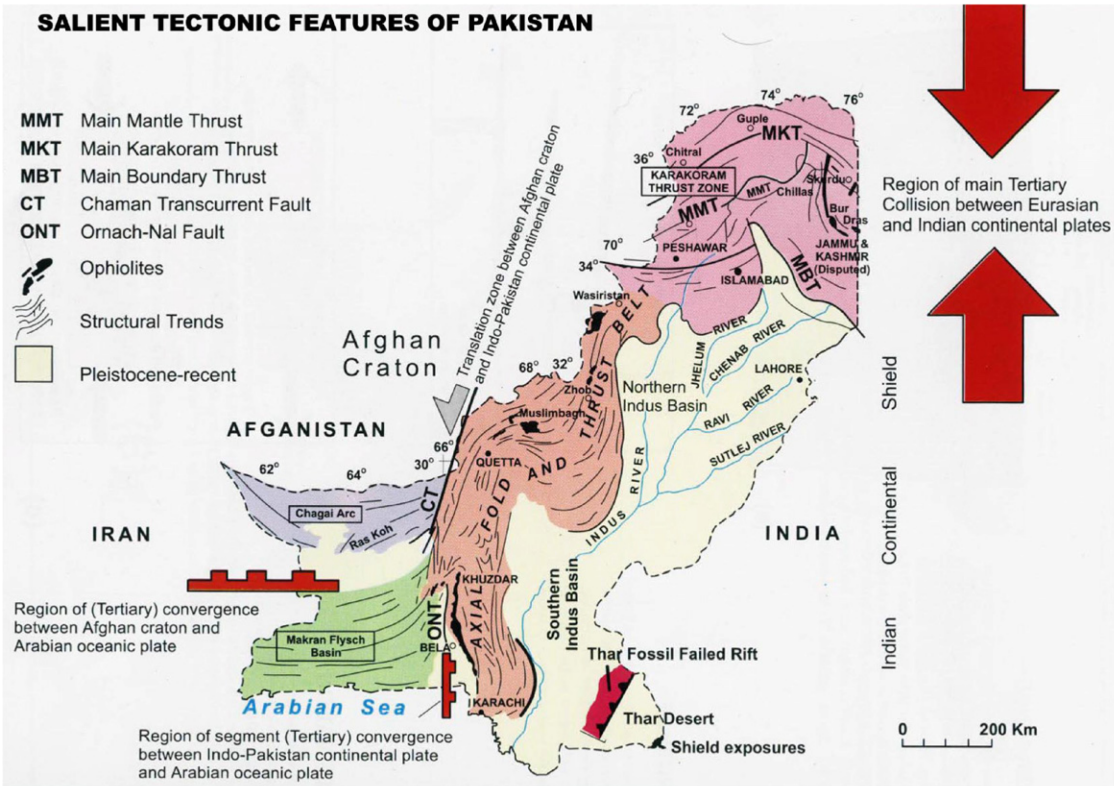

Fig. 2. Index map of Pakistan showing salient tectonic features (after Zaigham and Mallick [3]).

northward parallel with the Pakistan Fold-Thrust Belt. Further to the north approaching the Himalayas, they swing to the northeast before curving into the general ESE-direction of the Himalayas. The course of the tectonic elements is marked by the Main Boundary Thrust (MBT), the Main Mantle Thrust (MMT), and the Main Karakorum Thrust (MKT).

Tectonically, Pakistan is situated on the western-rifted margin of the Indo-Pakistan sub-continental plate. In the present plate tectonic setting, Pakistan lies partly on (i) the northwestern corner of the Indian lithospheric plate, (ii) the southern part of the Afghan craton, and (iii) the northern part of the Arabian oceanic subducting plate [3]. The eastern part of Pakistan represents (a) the Tertiary convergence with intense collision between the Indian and Eurasian plates in the north creating Karakorum Thrust Zone and (b) the translation between Indian continental plate and the Afghan craton in the north–west developing Chaman Transcurrent Fault System that connects the Makran convergence zone (where oceanic lithosphere is being subducted beneath the Lut and Afghan micro-plates) with the Himalayan convergence zone (where the Indo-Pakistan lithosphere is underthrusting the Eurasian continental plate).

The western part of the country also represents the Tertiary convergence between (i) the Arabian oceanic plate and the Afghan craton resulting Chagai Volcanic Arc and the Makran Flysch Basin and (ii) a segment of the Arabian oceanic plate and the western rifted margin of the Indo-Pakistan subcontinent causing obduction of the Bela Ophiolite Complex. All the major tectonic boundaries or the suture zones are distinctly traceable by the presence of numerous ophiolite occurrences.

3. Potential for geothermal energy sources

Most of the high enthalpy geothermal resources of the world are within the seismic belts associated with zones of crustal weakness such as plate margins and centres of volcanic activity. A global seismic belt passes through Pakistan, which has imprints of a long geological history of geotectonic events, e.g., which include: (i) Permo-carboniferous volcanism (Panjal traps in Kashmir) as a result of rifting of Iran–Afghanistan micropiates, (ii) Late Jurassic to Early Cretaceous rifting of the Indo-Pakistan Plate, (iii) wide-spread volcanism during Late Cretaceous (Deccan traps) attributed to the appearance of a "hot spot" in the region, (iv) emergence of a chain of volcanic islands along the margins of the Indo-Pakistan Plate, (v) collision of India and Asia (Cretaceous–Paleocene) and the consequent Himalayan upheaval, and (vi) Neogene–Quaternary volcanism in the Chagai District [4,5].

Nearly half of the developing countries have rich geothermal resources, which could prove to be an important source of power and revenue. Geothermal projects can reduce the economic pressure of developing country fuel imports and can offer local infrastructure development and employment. For example, the Philippines have exploited

local geothermal resources to reduce dependence on imported oil, with installed geothermal capacity and power generation second in the world after the United States. In the late 1970s, the Philippine government instituted a comprehensive energy plan, under which hydropower, geothermal energy, coal, and other indigenous resources were developed and substituted for fuel oil, reducing their petroleum dependence from 95% in the early 1970s to 50% by mid-1980s [6].

Similarly, in Tibet, which occupies more or less the same geological position in Himalayan mountain ranges as Pakistan, more than 600 surface indications of geothermal energy resources have been discovered with an estimated potential of 800,000 kW (Fig. 3). The Yangbajain Geothermal Power Station, the largest in China, started operation in 1988 sending annually about 50 million kWh of electricity to Lhasa, about 40% of the electricity turned out by the whole Lhasa grid, fully meeting the need of the local people. Exploitation of the geothermal energy resources in Tibet, though at its initial stage, has drawn the attention of world geologists and energy experts. Upon investigation, United Nations and Italian experts hold that the prospect is very promising and they have provided about $9 million as aid for the construction of geothermal fields in Yangbajain Nying Zhong, Naggu, and Latoggang [7].

Fig. 3. Geothermal manifestation, Ningzhong, Tibet [6].

The geotectonic framework suggests that Pakistan should not be lacking in commercially exploitable sources of geothermal energy. This view is further strengthened by (i) the fairly extensive development of alteration zones and fumeroles in many regions of Pakistan, (ii) the presence of a fairly large number of hot springs in different parts of the country, and (iii) the indications of Quaternary volcanism [8–13]. In Pakistan, these manifestations of geothermal energy are found within three geotectonic or geothermal environments, i.e., the geo-pressurized systems related to basin subsidence, the seismo-tectonic or suture-related systems, and the systems related to Neogene–Quaternary volcanism (Fig. 4).

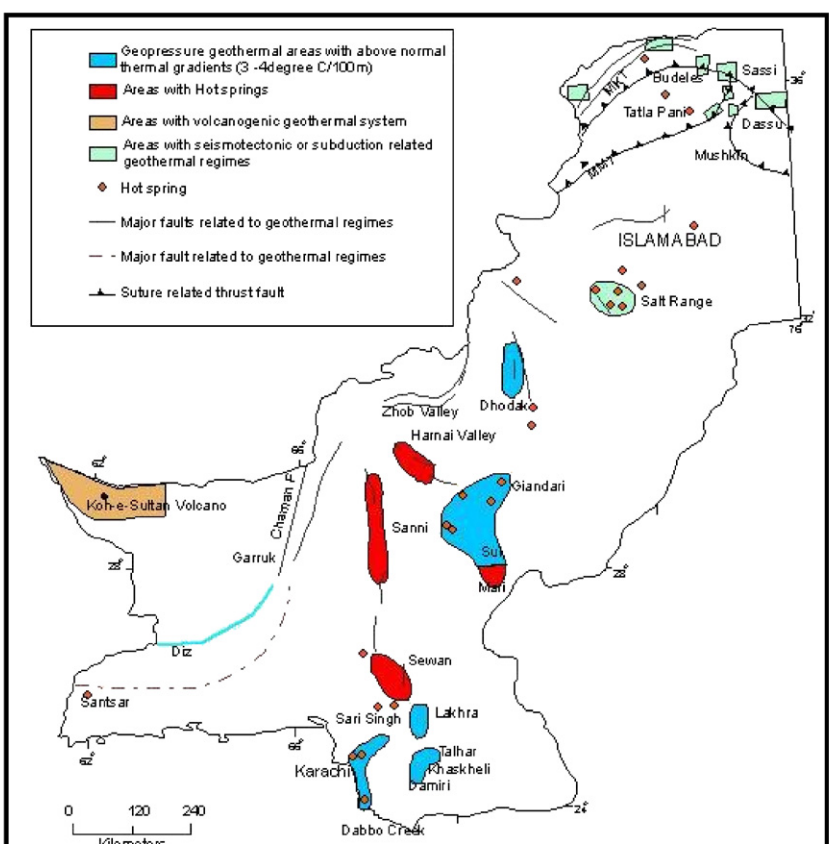

Fig. 4. Map shows the occurrences of geothermal sources in Pakistan (source: Geological Survey of Pakistan).

In general, the exploration of the geothermal sources addresses at least nine phases of integrated study [14], i.e., (i) identification of geothermal phenomena, (ii) classification of the geothermal field production field exists, (iii) location of productive zones, (iv) ascertaining a useful geothermal, (v) estimation of the size of the resource, (vi) determination of heat content of fluids that will be discharged by wells in the geothermal field, (vii) compilation of a body of data against which the results of future monitoring can be viewed, (viii) assessment of pre-exploitation values of environmentally sensitive parameters, (ix) determination of any characteristics that might cause problems during field development. In Pakistan, first three phases have so far been investigated on limited scale to study some of the baseline geological characteristics of the geothermal energy sources.

3.1. Geopressurized geothermal sources

In geopressurized systems, the normal heat flow is trapped by insulating impermeable beds in a rapidly subsiding sedimentary basin. It is an account of their great depth (as much as 6000 m) that encountered a relatively high temperatures ranging from less than 93 °C to more than 150 °C [15]. They commonly contain pressurized hot connate water at pressures ranging from 40% to 90% in excess of the hydrostatic pressure corresponding to the depth. Gradual subsidence has led to the ultimate isolation of trapped pockets of water contained in alternating pervious and impervious sequences.

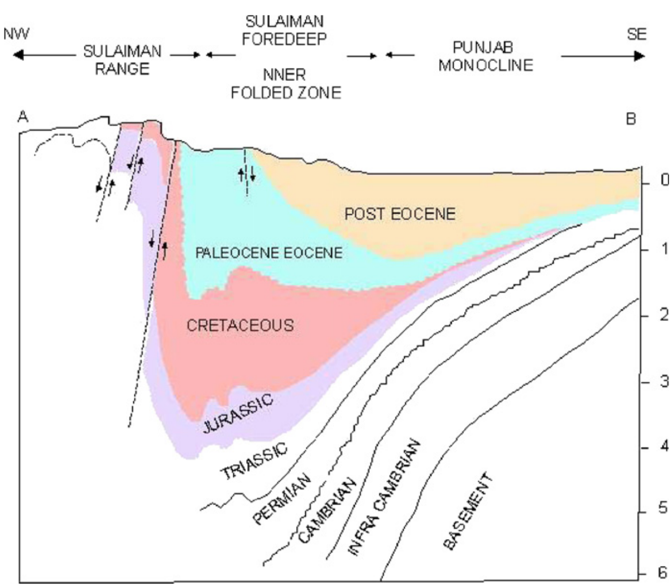

Fig. 5. Geologic structural cross-section of Sulaiman Foredeep.

In Pakistan, such geopressure zones are present within the Indus River basin particularly in Sindh province along the western margin of the Indus Plain and also in the Potwar Basin. The available information indicates the association of the geothermal zones with south-Sulaiman, south-Kirthar, and Lower Indus geological structures [16]. The southeastern part of the Sulaiman Foredeep shows the existence of the geothermal energy conditions (Fig. 5). The Sulaiman foredeep geothermal zone has the deepest burial of over 15 km sedimentary pile [17], which is seismically active. A number of earthquakes with magnitudes 3–7 on the Richter scale have been recorded associated with the deep seated faults. Many lineaments have also been traced on the surface [18], which probably are the reflections of basement faults. The great thickness of sediments and depth of burial seem to have generated exceptionally high geothermal temperatures at depth as evident from the leakage of thermal water through the faults, fractures or fissures at Giandari, giving the impression of the presence of a "warm spot" beneath Giandari. In the southernmost region of the foredeep, an abnormally high thermal gradient of 4.1 °C/100 m is encountered in the Giandari oil and gas well [19]. Likewise, the neighbouring oil and gas wells at Sui and Mari have also recorded higher than normal geothermal gradients of about 3.0–3.49 °C/100 m. Farther northward, the well at Dhodak has similar thermal gradient. In this region, thermal springs have been recorded at Uch and Garm Ab at the foot of Mari Hills, Zinda Pir, Taunsa, and Bakkur [20,21].

In the south-Kirthar geothermal zone, the oil and gas wells drilled at Lakhra show thermal gradients above normal (3.3 °C/100 m). Farther southward, the oil and gas wells at Sari and Karachi revealed a geothermal gradient of about 3.0 °C/100 m. In Karachi, two hot springs exist: one at Mangho Pir and the other at Karsaz. The physical and chemical characteristics of Karachi hot springs have been summarized in Table 1. The geological setting of the south-Kirthar geothermal zone is similar to that of the south-Sulaiman geothermal zone. Based on the analytical results of aeromagnetic anomalies associated with the southern Indus basin, it is delineated that the Kirthar zone also includes a depression containing a pile of sediments 6–10 km thick. This sedimentary basin is associated with the fossil failed-rift [22]. The rifted basement beneath the sedimentary depression shows prevalence of higher

Table 1
Physical and chemical characteristics of Karachi hot springs (after Todaka et al. [27])

Hot spring locality	Temperature (°C)	pH	Electric conduction (μ/cm)	Feature of hot water	Geology
Karachi					
Mangopir	50.3 (Ambient temperature 36.0)	7.45	2380	Colourless, ordorless	Surface soil CO_2 gas bubbling
Karsaz	39.0 (Ambient temperature 5.4)	7.87	7910	Colourless, H_2S smell	CO_2 gas bubbling

compression caused most likely by the anticlockwise rotational component of the Indo-Pakistan continental plate. The region is seismically active and epicentres of shallow earthquakes ranging in magnitude from 3 to 5 on Richtcr scale have been recorded.

The Lower Indus trough and the offshore geothermal zone are characterized by geothermal gradients above normal, which were encountered in borehole drilled for the oil and gas exploration. The well Damiri-1 had a geothermal gradient of 4 °C/100 m [19], whereas the wells at Talhar and Khaskheli have encountered geothermal gradients in the range of 3.0–3.5 °C/100 m. The offshore well at Dabbo Creek revealed a geothermal gradient of 3.7 °C/100 m. The southern part of the Lower Indus trough forms a rifted monocline (Fig. 6) containing a prism of sediments ranging in age from Triassic to the Neogene [23].

3.2. Seismo-tectonic and suture-related systems

Geothermal regimes in the northern part of Pakistan, as manifested by many thermal springs, are associated with sutures and related structures. This part of the country is comprised of Karakorum, Hindukush, and Himalyan thrust mountainous belts, which show very strong seismic activities. The hot spring sites of Chitral region are associated with the Hindukush fault system. In Gilgit-Hunza region the hot springs of Murtazabad, Budelas, Sassi, and Dassu are associated with MKT, whereas the hot springs of Tatta Pani and Mushkin are associated with the MMT. As to the heat sources, the obvious evidence such as the existence of a young volcano is not found in this part of the country. However, the heat generated due to the friction along the MKT, MMT or the Hindukush fault systems and also due to radioactive decay of the Karakorum granodiorites are likely the source of heat giving rise to the thermal springs. Fig. 7 shows a schematic model for the hot springs associated with the MKT, which could be applied to other fault-associated hot spring of the area.

In Garm Chashma valley about 50 km northwest of Chitral, thermal springs are located within the Reshun and Ayun fault domain. These springs are near the contact of

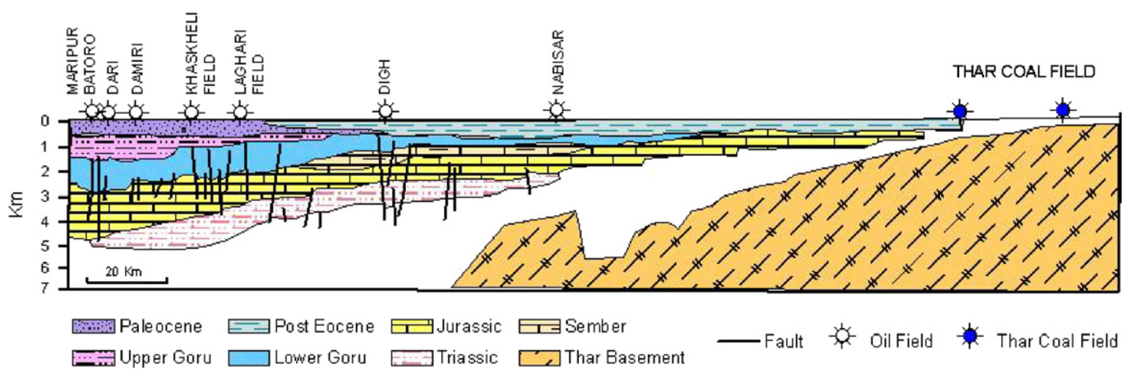

Fig. 6. Geologic structural cross-section of rifted monocline in southern part of lower Indus trough (after Zaigham et al. [23]).

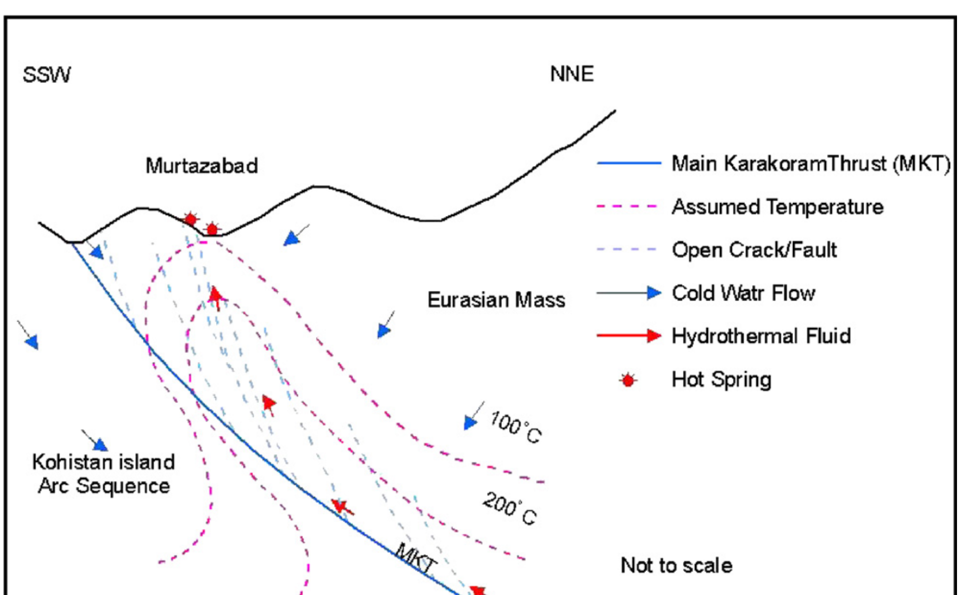

Fig. 7. Schematic model for hot spring occurrences on Karakorum–Himalayan thrust zone (after Todaka et al. [27]).

the granites intruded in metasediments [24] in a region of extremely high seismicity. Another hot spring is reported near the snout of Pechus glacier, about 105 km northeast of Mastuj [21], which is located near the contact of granite intruded in Cretaceous metasedimcnts. In Yasin District, a hot sulphurous spring is located 3 km north of Rawat Village oozing from the metasedimcnts of the Darkot Group.

In the western part of the Hunza Valley, the thermal springs are associated with the geothermal system of the MKT. One cluster of five springs is near Murtazabad village, which is situated within 7 km of the MKT. The water temperature of these springs ranges from about 26 to 91 °C [25]. The reservoir temperature at this site has been estimated to range from 198 to 212 °C. Farther to the southeast, in the Skardu District, two sulphur springs and three hot springs have been reported in the Dassu area. The maximum water temperature of these springs is 71 °C. They are also located in the vicinity of the MKT, close to granitic rock. The geological conditions in the Dassu are similar to those of Murtazabad and Budelas.

The geothermal system related to the Nanga Parbat–Haramosh Massif forms hot springs along the faulted margins of the massif. On the eastern side, there is a hot spring near Mushkin associated with the MMT. The water temperature is about 57 °C. The estimated reservoir temperature (silica geothermometer) ranges from 86 to 90 °C [26]. Physical and chemical characteristics of the hot springs oozing in the northern part of the country have been summarized in Table 2.

There are number of hot water springs in the Tatta Pani area, arranged in a row spreading over a distance of

Table 2
Physical and chemical characteristics of hot springs in northern Pakistan (after Todaka et al. [27])

Hot spring locality		Temperature (°C)	Flow rate (l/min)	pH	Electric conduction (μ/cm)	Feature of hot water	Geology	Remark
Northern Part of Pakistan								
Murtazabad	N1	42.3 (Ambient temperature 35.0)	33	7.5	1720	Colourless, odorless, tasteless	Terrace deposit Garnet staurolite schist (Baltit Group)	Bathing and cloths washing
	N2	36.9 (Ambient temperature 33.5)	6.7	7.8	–	Colourless, H_2S smell, sour taste	Surface soil terrace deposit Garnet staurolite schist (Baltit Group)	Washing for prayer
	N3	30.0 (Ambient temperature 28.0)	500	9.21	2470	Colourless, H_2S smell	Surface soil terrace deposit Garnet staurolite schist (Baltit Group)	Boiling temp. is 92 °C; $CaCO_3$ deposition
Budelas	N8	46.0 (Ambient temp. 32.0)	100	7.85	1540	Colourless, H_2S smell, salty taste	Talus/Garnet mica schist (Baltit Group)	Bathing
	N9	36.0 (Ambient temperature 17.0)	100	7.49	77.6	Colourless, H_2S smell	Talus/Garnet mica schist (Baltit Group)	Junction of two rivers
	N10	Near boiling temperature (91)	—	7.64	1160	Colourless, H_2S smell	Talus/Garnet mica schist (Baltit Group)	Junction of two rivers
Tata Pani	N4	83.0 (Ambient temperature 17.0)	More than 621	8.83	1060	Colourless, H_2S smell, salty taste	Terrace deposit/fractured amphibolite (Kamila amphibolites)	–
	N5	65.5 (Ambient temperature 36.5)	800	8.57	1540	Colourless, H_2S smell, salty taste	Terrace deposit/fractured amphibolite (Kamila amphibolites)	–
	N6	78.0 (Ambient temperature 36.5)	More than 100	718	–	Colourless, H_2S smell, salty taste	Terrace deposit fractured amphibolite (Kamila Amphibolites)	–
	N7	80.0	34	8	–	Colourless, H_2S smell, salty taste	Talus/fractured amphibolites (Kamila amphibolites)	–
Mashkin		57 (Ambient temperature 34.4)	1	7.87	1070	Colourless, H_2S smell	Surface soil/Gneiss (Nanga Parbat Gneisses)	Cloth washing
Sassi		54.0 (Ambient temperature 33.0)	–	7.87	1310	Colourless, odorless	Talus/Gneiss (Kohistan Island are sequerice)	$CaCO_3$ deposition
Chu Tran		43.9	200	7.74	5090	Colourless, odorless	Talus/Limestone (Eurasian Mass)	$CaCO_3$ deposition bathing use

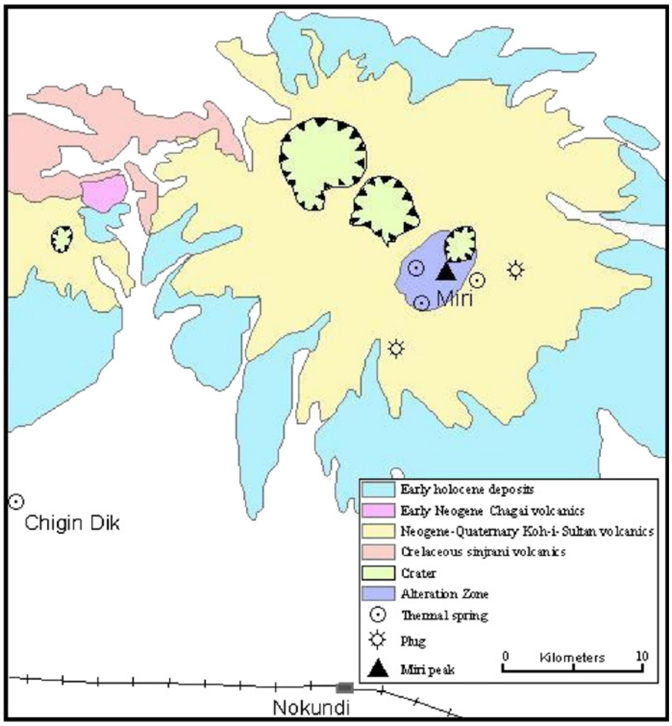

Fig. 8. Geological sketch map of the Koh-e-Sultan volcanogenic geothermal zone.

about 8 km. They emanate from Quaternary terraces and colluvial deposits. Amphibolites fractured by the MMT constitute the hard rocks exposed around these geothermal manifestations. Moreover, hot springs also emanate from the Raikot fault zone along the western margin of the Nanga Parbat–Haramosh Massif at Sassi and at Tatta Pani, along the Indus River. Sass spring has a field temperature of 54 °C, whereas the reservoir temperatures range from 40 to 48 °C [27].

In other parts of the Indus and Balochistan sedimentary basins, the geothermal manifestations in the form of hot springs are scattered and directly or indirectly associated mainly with the seismotectonic and suture zones. Three hot springs are located in the foothill region of the Kirthar Range west of Dhadar, near Sanni, and south of Thal (Fig. 4). They appear along the Mach and Kirthar faults [18] at the northwestern edge of the Kirthar Range which has a pile of sediments more than 10 km thick. This is also a region of high seismicity [28]. In the Harnai valley, prominent thermal springs are located associated with the Harnai and Tatra faults, where earthquakes of magnitudes 6 to over 7 on Richter scale have been recorded [18,21,28]. Similarly, two hot springs are located north of the Zhob valley, which occur amidst a series of imbricated faults in a region of relatively high seismicity.

Table 3
Physical and chemical characteristics of hot springs in Chagai Volcanic Arc (after Todaka et al., 1999)

Hot spring locality		Temperature (°C)	Flow rate (l/min)	pH	Electric conduction (μ/cm)	Feature of hot water	Geology	Remark
Chagai Volcanic Arc								
Chicken Dik	C1	29.9 (Ambient temperature: 40.9)	–	6.58	>10,000	Colourless, odorless salty taste	Recent deposits	$CaCO_3$ deposition
Koh-e-Sultan Voleanies	C2	29.5 (Ambient temperature 34.7)	<1	7.44	1060	Colourless, ordorless salty taste	Basal agglomerate	Discharge from river bed
	C3	32.2 (Ambient temperature 38.6)	<1	6.89	>10,000	Colourless, odorless salty taste	Basal agglomerate	CO_2 gas bubbling $CaCO_3$ deposition. Discharge from river bed
	C4	32.0 (Ambient temperature 36.9)	<1	6.7	–	Colourless, odorless salty taste	Basal agglomerate	CO_2 gas bubbling $CaCO_3$ deposition. Discharge from river bed
	C5	26.9 (Ambient temperature 31.1)	<1	2.77	>10,000	Colourless, H_2S smell	Altered andesite	Sulphur and Salt deposition. Discharge from river bed
	C6	25.5 (Ambient temperature 31.9)	–	2	–	Colourless H_2S small	Altered andesite	Sulphur and Salt deposition. Discharge from river bed
	C7	27.5 (Ambient temperature 35.9)	10	7.13	>10,000	Pale brown odorless salty taste	Basal agglomerate	Water contains Fe. Discharge from river bed

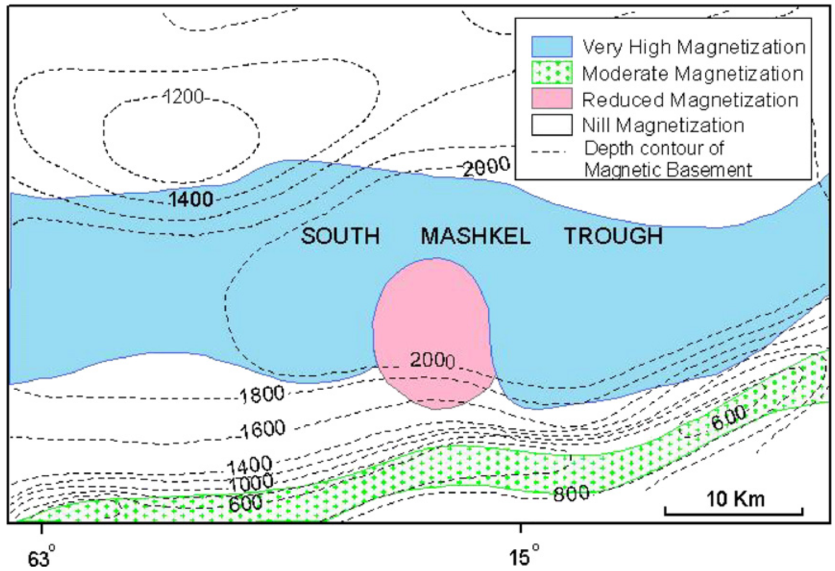

Fig. 9. Map showing the magnetization and the depth contours in the Kharan trough.

3.3. Geothermal systems related to Neogene–Quaternary volcanism

Geothermal systems associated with the Chagai Magmatic Arc are manifested by mineralized thermal springs, which are largely confined to the Koh-e-Sultan volcano in the vicinity of the Miri crater (Fig. 8). The water temperatures of the springs, which range from 25.6 to 32 °C, are lower than the ambient temperature in summer season. An acidic alteration zone has formed southwest of the Miri peak. A part of this zone is strongly silicified. Hydrogen sulphide was observed at places as there are scattered sulphur deposits in the alteration zone [12]. In the Koh-e-Sultan geothermal system, the reservoir temperatures estimated on the basis of the silica geothermometer range from 150 to 175 °C [25]. This region apparently has the highest geothermal potential in Pakistan and as such economically exploitable geothermal reservoir(s) may be expected in the southwestern part of the Koh-e-Sultan. Preliminary physical and chemical characteristics of these geothermal springs have been summarized in Table 3.

The aeromagnetic investigations were carried out in large areas of Chagai Volcanic Arc, the Kharan Trough and the Axial Fold-Thrust Belt of Pakistan [29,30]. The results of the analytical studies of the Chagai Volcanic Arc and the Kharan aeromagnetic anomalies have revealed a number of buried volcanic plugs, necks and stocks all over the Chagai region, which could be very important targets for the exploitation of geothermal energy [31]. Similarly, high-magnetic zones have also been observed in Kharan area striking in east–west direction almost parallel to the Chagai Volcanic Arc. The most important subsurface crustal feature revealed by the aeromagnetic anomalies is the distinct presence of a large semi-circular embayment of reduced magnetization within the zone of high-magnetic anomalies, which is known as south Mashkhel Magnetic Belt (Fig. 9). Estimated depth to the reduced magnetic embayment is estimated to be 2000 m. The shape of the crustal feature is suggestive of a plug-like regional intrusive. The reduction in magnetite content, compared to adjacent rocks in the hosting magnetic belt, is suggestive of rocks that are felsic in composition, i.e., high in quartz content. The tensor analyses of seismicity events of the areas also show rifting conditions beneath the Kharan trough [32]. Such rifting process may cause consequent upwelling of mantle creating excessive heat regime within the trough. This intrusive-like body appears to be a very good source of geothermal heat.

4. Conclusion

The present study of the geotectonic framework suggests that Pakistan should not be lacking in commercially exploitable sources of geothermal energy. This view is further strengthened by (a) the fairly extensive development of alteration zones and fumeroles in many regions of Pakistan, (b) the presence of a fairly large number of hot springs in different parts of the country, and (c) the indications of Quaternary volcanism associated with the Chagai arc extending into Iran and Afghanistan border areas. However, a few localities, scattered sporadically all over the country, have so far been studied to evaluate only some of the basic characteristic parameters of the geothermal prospects. The present review study of these geothermal prospects reveals the viability to undertake the detailed feasibility studies of some of the prospective sources for the generation of sustainable indigenous energy in areas where the geothermal energy sources exist.

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